California Department of Water Resources
FINAL REPORT

Findings and Recommendations to Develop the Six-Year Activity Plan for the Department's Drainage Reduction and Reuse Program

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EXECUTIVE SUMMARY

The primary purpose of this contract was to compile documentation of the state of knowledge and understanding of drainage water reuse studies, research and demonstration projects. This was to help identify appropriate technologies that can be recommended for implementation at the farm level. Findings and recommendations of this work are to be used to develop the six-year activity plan for the Department of Water Resource Drainage Reduction and Reuse Program. The specific objectives of the work were (1) to collect, analyze and evaluate published reports and unpublished data on studies, field experiments, and demonstrations on the reuse of agricultural drainage water for irrigation in the drainage problem areas of the western San Joaquin Valley, and (2) to identify and prioritize the need for additional study, research and field demonstration proposals and projects that should be implemented in the next 6 years.

A review of some aspects of the scientific basis for drain water use for irrigation is presented before reviewing specific field research and demonstration projects. Key items identified in the scientific basis section include the fact that models have been developed which will allow the simulation of (1) crop yield, (2) amount and concentration of water leaving the root zone, and (3) salt and water distributions within the root zone on a temporal basis based on the salinity and amount of irrigation water applied. The model can be used to simulate the behavior for any crop for which salinity crop tolerance coefficients have been established.

Groundwater hydrology, particularly as it relates to the amount and chemical composition of water collected in subsurface drainage systems, is of paramount importance in understanding the present and long-term consequences of irrigating with saline water. Although models and other theories can be used to estimate the concentration of water moving below the root zone, the concentration of water collected in the drainage system can differ dramatically from the concentration leaving root zone. This is the result of the path that water takes after it leaves the root zone towards the drain line. Water midway between two drainage lines will sweep tens of feet below the water table before ascending up into the drain line. Water originating closer to the drain line will arrive at the drainage line at a shorter time.

The significance of these travel times as related to the western San Joaquin Valley is as follows. The alluvial materials historically originated below the sea and therefore contain high concentration of salts and other elements associated with a marine environment. The water collected in a drainage system is a combination of the groundwater and water that has left the root zone. If the field has been irrigated with nonsaline water, the drainage water collected will, in most cases, contain a higher quantity of salt than was applied with the irrigation water. In a sense the historic salts are being "mined" and brought to the surface with the drainage water. Because of the huge reservoir from which drainage waters are derived the rate of dissolution of precipitated salts such as gypsum and the large travel times, the "excessive" salts can be mined for several decades or centuries. This is the reason that selenium continues to be removed in the drainage water even though the fields have been irrigated for years with water with almost no selenium. In one sense, because the salts and chemicals such as selenium

contained in the drainage water exceeded the amount that was applied with the irrigation water; the groundwater quality could be considered to be improved by irrigation and drainage.

When saline waters are used for irrigation and become highly concentrated before they leave the root zone, the captured water in the drainage system will contain less salt than what left the root zone. In this case, salts are being added and "stored" in the groundwater system. This process causes salts to accumulate in the groundwater which will eventually result in a continual increase in the concentration of the drainage water.

From a salt balance point of view, imported irrigation waters also import salt. Reusing drainage waters for irrigation results in a continual accumulation of salts. However, because of the large reservoir for salts in the groundwater the consequences of adding additional salts will be manifest in a very slow manner.

Another significant scientific principle is that the evapotranspiration rate is dependent upon the plant size as well as the climate. Reducing the plant size reduces the transpiration. Therefore, if a plant is stressed by salinity, less water will be transpired than expected. This was a significant factor in the utility of eucalyptus trees to dispose drainage water.

The initial concept for disposing drainage water was to use eucalyptus trees to transpire water and produce a marketable product. Numerous plantings of eucalyptus were made throughout the Valley. Some of the plantings were simply to test various clones. In general, eucalyptus trees have not proved to be effective for drainage water disposal in the western San Joaquin Valley. The major deterrents were (1) lower salt tolerance than originally anticipated, (2) susceptible to frost damage, and (3) susceptible to low oxygen status associated with wet soils. Based on the salt tolerance of eucalyptus, the salinity level of drainage water and the leaching fraction that could be achieved under the soil conditions, the trees only transpired from 60 to 70 per cent of the potential transpiration. Efforts to increase the leaching fraction by applying more water negatively affected the plants by inducing low oxygen status in the soil. The accumulated effects of all these factors, is that eucalyptus are no longer considered to be a crop used for drainage water disposal.

Two major drainage water use demonstration projects have been established at a site near Mendota and at the Red Rock Ranch. The Mendota Project was initiated in approximately 1986 consisting of trees, most of which were eucalyptus. A few halophytes were also investigated at that site. The frost in 1990 killed the eucalyptus trees and the project was reinitiated in approximately 1992. The more recent demonstration included trees, halophytes and an evaporator pond.

The design of the Red Rock Ranch project was guided by results from the Mendota site. A significant feature of the Mendota site study was that it was conducted on relatively small plots with drain lines placed immediately below the plots and a very low permeable clay layer existing ten to twelve feet in depth. Under these conditions, the chemical composition of the drainage water would be very similar to that leaving the root zone. However, the data from the halophyte plots at Mendota suggest some complex subsurface hydrological effects which negates meaningful interpretation of the composition of the drainage water collected under the halophytes. For example, the salt concentration in the drainage water was equal to the salt concentration of the irrigation water applied without any concentrating effect from evapotranspiration. At the same time, the total mass of salts collected in the drainage lines was approximately half of the total mass of salts applied to the plants.

The Integrated Farm Drainage Management Project (IFDM) was conducted on 640 acres at the Red Rock Ranch. Initially, the soil salinity on this land was high and productivity very low. The concept was to install subsurface drainage lines which would allow the reclamation of the land by leaching with good quality water, so that salt sensitive crops could be grown. Approximately 75 percent of the farm was to be used for growing salt sensitive crops. The drainage water was then to be sequentially used on an area growing salt tolerant crops, followed by salt tolerant trees which were later planted to salt tolerant grasses, followed by halophytes and ultimately disposal in a solar evaporator. The entire concept was to collect dry salts in the solar evaporator which could, after some processing be marketed at an economic value. The concept of an evaporator pond is to apply water only at the rate at which it evaporates, thus not ponding any water to attract water fowl.

Reclamation of 75 percent of the farm was successful, and the land has been productive for growing a range of crops. One of the most significant findings from the Red Rock Project is verification of the significance of travel times for water reaching drainage lines. More salt was collected in the drain lines than was applied with irrigation water. In the salt sensitive areas there was net removal of salts from the groundwater. With the sequential reuse of drainage water, the total amount of salt in the drainage water was less than was applied by irrigation. Thus, there was a net increase of salinity added to the groundwater as the drain water was sequentially used. At the end only about six percent of the salt was deposited in the evaporator pond as compared to the expected amount based on salts added to the farm. In a consistent manner, the salt concentration in the drainage water only rose gradually from 8,011 to 8,872 to 12,016 to 11, 189 mg/L with each sequential reuse. None of the drainage waters was sufficiently concentrated, requiring the use of halophytes. Of critical importance, however, is the fact that salts added to the groundwater system will eventually be returned in the drainage waters. Thus one can expect a gradual long term increase in salinity of the drainage waters which constrains the sustainability of the system.

The experience at Red Rock Ranch has focused the complexity of properly designing an evaporator pond. The design of an evaporator pond to prevent any ponding is extremely complex. One would need information on the temporal variations in evaporation rate (which would vary annually), and drainage water volume. These data could be used to calculate the pond area that would evaporate all the water delivered daily. This constraint dictates that the pond be large and rather inefficient because much of the time the potential for evaporation is likely to exceed the rate of water discharge.

The pond size could be made more efficient if there was a large capacity to store drainage water and then deliver it on a daily basis consistent with the evaporation rate. Another factor which largely constrains the utility of evaporator ponds is that salts do accumulate. They are dissolved creating a very high concentration by rain water collected in the pond. Since rain is associated with low evaporation rate, very concentrated water could exist in the pond for some period of time during a rainy season. The concentration of selenium can exceed 1 mg/L which creates a violation of the Toxic Pits Act.

Periodic episodes of excessive water containing selenium in the halophyte and evaporator pond area, creating some bird damage has jeopardized the drainage discharge permit. Efforts are presently underway to adjust the system to be within environmental compliance.

The Grasslands area farmers have the benefit of being able to discharge drainage water into the San Joaquin River as long as they meet discharge limits. The magnitude of the discharge limits, however are decreased yearly. Largely through improved irrigation management the Grasslands farmers have been able to reduce discharge into the river by about 40 percent. Some reduction has been achieved by blending drainage water into the main surface water supply. For example, Panoche Drainage District blends drainage water into their canal water to a level of 600 ppm total dissolved solids. This water is suitable for growing all crops in the area. Direct drainage water reused (with possibly minor blending) on forages has recently been tested in various Grasslands projects. However, these efforts are in their initial stages and it is too early to draw any firm conclusions.

Available information on salt tolerance of a large number of diverse crops is presented in the report. The main conclusion is that there are numerous crops that could be considered for irrigation with saline waters. A large range of management options are available for farmers to cope with the salinity/drainage issue. The ultimate selection should be based on the economically optimal set of choices.

Although there is much scientific information available to guide the management of the salinity/drainage issue in the western San Joaquin Valley, there are areas where additional research is justified.

Management to reduce drainage volumes is firmly recognized as a positive management option. Great progress has been made towards modifying irrigation to reduce drainage volumes. An additional option to be explored, however is to have an active control on the drain line outlet. Some of the advantages of controlling the drainage outlet are to store water in the profile for potential crop use, or for discharge on a more timely basis to disposal sites. Also, control of the drainage outlet will alter hydraulic gradients which potentially could reduce upslope to downslope water migration and also increase downward migration of water below the field. The required research is more than engineering to develop the control systems, the research should be directed towards the total management practices including a monitoring technique to determine when and how much leaching is required on a timely basis.

The data particularly at Red Rock Ranch clearly illustrate the complex interaction between water and chemicals leaving the root zone and then being collected in the drainage lines. The underground hydrology including travel times to drainage lines needs to be more quantitatively established. This analysis is critical to project the long-term consequences of using drainage water for irrigation. Because of the complex geologic system accurate quantitative projections cannot be reasonably expected. Nevertheless, reasonable projected estimates are important in guiding policy decisions relative to short-term benefits and long-term consequences of agricultural drainage water reuse.

Numerous combinations of management options are available. Each combination of options invokes a set of costs and benefits. Additional economic analysis to identify the economically optimal combination of management is required for planning purposes. The research identified, however is important for providing accurate input information into the economic analysis.

Whether boron is going to be a limiting factor in the reuse of drainage waters is presently disputed. This question needs to be more firmly resolved. Additional information is important on; (1) relationship between visual leaf symptoms and yield associated with boron damage, (2) dynamic interacting relationships between boron concentration in irrigation water, adsorption of boron, boron uptake, boron effects on yield, and the leaching of boron, and (3) whether boron damage will ever exceed salinity damage when using saline drainage water.

Reusing drainage water is building up the salinity in the groundwater which will have long term consequences from a sustainability point of view. A salt balance, whereby salts added equals salts removed, with proper consideration for precipitation or dissolution of salts, is necessary for sustainable agriculture. Since salts are imported with irrigation water, a means of ultimately isolating salts from productive agricultural fields is required for sustainability. One option is to transport the salts out of valley. This option has strong political opposition. The only in-valley solution is to place the salts in evaporation ponds. However, this option is constrained by selenium and the damage to wildlife.

Therefore, basic research to reduce the ecological hazard of surface waters containing selenium is important. Additional basic information on selenium food chain transfers and ecotoxicological hazard is critical. This research might include evaluation of brine shrimp or other invertebrate harvesting to interrupt the food chain.

Because selenium is the toxicant of concern, extended research to develop practical selenium removal methods is justified. The initial results of flowing water through hay bales to greatly reduce the selenium concentration are promising but needs additional testing and refinement.

Science can provide the information to guide management and policy decisions. Science may even be able to project the long-term consequences of a policy decision, however science alone is inadequate because science does not include human or economic values that underlie the decisions societies make. The major policy issue in the present context is the trade off between short-term benefits of reusing water with the long term serious consequences of degrading the groundwater and land. Mesopotamia is the often repeated classic example about a society that transformed very productive agricultural land into a desert. A consideration that is frequently overlooked is that this transition occurred over centuries of time. Because it took centuries of time, rather than decades was it any less an historical disaster?

INTRODUCTION

The primary purpose of this contract was to compile a documentation of the state of knowledge and understanding of drainage water reuse studies, research, and demonstration projects. The purpose was to help identify appropriate technologies that can be recommended for implementation at the farm level. Findings and recommendations of this work are to be used to develop the sixth-year activity plan for the Department of Water Resources Drainage Reduction and Reuse Program.

The specific objectives of this work were: (1) to collect, analyze and evaluate published reports and unpublished data on studies, field experiments and demonstrations on the reuse of agricultural drainage water for irrigation in the drainage problem areas of the western San Joaquin Valley and (2) to identify and prioritize the need for additional study, research and field demonstration proposals and projects that should be implemented in the next 6 years.

A vast array of resources were utilized in compiling this report. Several individuals whose names are listed elsewhere in this report were interviewed. Quarterly, annual and final reports on projects and/or contracts on water reuse studies were very helpful in documenting results of studies which have not been published in technical journals. Four boxes of material stored at the DWR Fresno Office were shipped to us. These boxes contained a variety of documents. There was a collection of research papers and other general information on trees, halophytes, or other plants that might be useful for irrigation with saline drainage water. There was a collection of San Joaquin Valley Drainage Water data. Of particular value where the raw data and field notes on various agroforestry case studies established in the Valley. This material provided "new" information not included in other reports or generally available.

The challenge of sustaining agriculture in irrigated, semi-arid regions of the world where salinity is an issue can be documented back to the early recorded history of society. Extensive research has been devoted to this topic. Indeed, some countries established national laboratories specifically dedicated to the research of soil salinity related issues. Among these is the USDA-ARS, George E. Brown Jr. Salinity Laboratory located at Riverside, California. Therefore, extensive research information on irrigation with saline waters is available. The presence of selenium in the drainage water is a unique feature associated with the problem in the western San Joaquin Valley that has not been addressed in previous generations. Indeed, the presence of selenium places tremendous constraints on the various options available for managing drainage waters.

The first section of this report will provide a scientific basis for drain water use for irrigation. This section will contain the basic information which can be compared to and in some cases, explain the results of the field demonstration projects.

This report will be organized based on the following rationale. The initial promoted means of using drainage water for irrigation was on trees with the greatest emphasis placed on eucalyptus trees. The term "agroforestry" was utilized to describe this approach. Therefore, the first section following the scientific basis will review the various cases where trees were planted on various locations. A more completely designed and monitored system on drain water reuse for irrigation was established at a Mendota Site. A description of the project and report on the major findings will be included in the next section of the report. The establishment of the Integrated On-Farm Drainage Management (IFDM) program at the Red Rock Ranch was initiated following the Mendota Site project and will be the next section of this report. The Grasslands Bypass Project whereby farmers in the Grassland areas, have developed management plans to meet selenium load discharge limits into the San Joaquin River is a more recent development and will be summarized in a section following the Red Rock Ranch Demonstration.

A major section of this report will review what is known of several crops which might be considered to be irrigated with saline waters. The section will cover agronomic crops, vegetable crops, forages, trees and halophytes.

The final section will provide a brief assessment of research needs.